International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 6 Issue 7|| July 2017 || PP.55-65

Regional Flood Frequency Analysis: A Case Study Of Sabarmati River Basin

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Abstract: *The study involves estimation of flood data that are unavailable for ungauged sites of Sabarmati basin existing in the state of Gujarat. The procedure here involves development of a relationship between the annual peak flood data and the catchment area for an ungauged site and thereafter accordingly study and provide output in form of design flood data for various return periods at ungauged sites that are inappropriately or not at all gauged properly which is useful for design of hydrological structure at that site. It involves performing through analysis of the data available for minimum 7 gauging sites for at least 10 years using the index flood method of analysis and then plotting a flood frequency curve for the Sabarmati basin further it would also involve providing a proper scale to the graph plotted. The above procedure would also involve certain dummy sites which would be used preliminarily just to test the methodology adopted for performing the analysis.*

Keywords: *catchment area, frequency curve, homogeneity test, flood index method, return period*

Date of Submission: 10-07-2017 Date of acceptance: 28-07-2017

I. INTRODUCTION

Flood frequency estimates are useful to us in a variety of ways starting from the construction of hydrological structures, maintenance and even safety of the people at the time of extreme conditions. Thereby there are two such approaches which can help us estimate the data as per our requirement. One such approach is the deterministic approach where the working of the total process from the start till the end is assumed on terms that are predefined. Another term that is used in estimation of data is named the statistical approach which is more related towards an analytical approach where principles of statistics are applied for solving the uncertainties that arise during the establishment of relationship between data which characterizes to be more dynamic in nature.

The data that is to be used in the above described processes is available in two different forms the first one is in the form of forecasting wherein future predictions are made in terms of discharge or for that matter any other data that is in relation with a particular catchment. The other form is named prediction which is more related to the future aspects of a certain catchment in relation to the return of period of certain flood etc.

II. LITERATURE REVIEW

Sathe et al.(2012) suggested “Rainfall analysis and design flood estimation for Upper Krishna River Basin Catchment in India ”,they carried out flood frequency analysis of Upper Krishna river basin using flood index method. This method consists of fitting a theoretical extreme value probability distribution based on flood data of gauging sites and then utilizing it to estimate flood data of ungauged site for various return periods which could be used for design for design of hydrological structures.[1]

Basu and Srinivas (2016) proposed “Regional Flood Frequency Analysis using Entropy-Based Clustering Approach” ,they carried out Entropy Based Clustering Approach(EBCA) to identify regions by accounting for outliers and recommended applying a recently proposed RFA approach on the regions in four major rivers basins (Mahanadi ,Godavari ,Krishna , and Cauvery) of India for flood estimation and found that EBCA approach was more effective than conventional approach in terms of regional homogeneity and reliable flood estimation for ungauged sites.[2]

Kar et al. (2012) presented “Application of Clustering Techniques Using Prioritized Variables in Regional Flood Frequency Analysis-Case Study of Mahanadi Basin”, they classified influential site characteristics and then clusterized basin region using various clusterizing techniques to test the homogeneity of region. Then they used L-moment algorithm to identify frequency distribution curve and carried out flood estimates of the basin and compared it with its previous results.[3]

Xiao et al. (2009) proposed “Design Flood Hydrograph Based on Multicharacteristics Synthesis Index Method”, they developed MSI method to describe flood hydrographs in an integrated way by considering multiple characteristics. In these MSI these multiple characteristics into single characteristic according to weights determined by CRITIC method and Annual maximum flood hydrographs are converted into MSI series. The quantile of these MSI series is estimated using conventional flood frequency analysis and design flow hydrograph could be derived from this quantile.[4]

Parkes and Demmerit (2016) presented “Defining the hundred year flood:A Bayesian approach for using historic data to reduce uncertainity in flood frequency estimates”, described Bayesian model is able to reduce the level of uncertainties in a certain river basin solely just by historical data compared to other methods of flood frequency analysis.[5]

Basu and Srinivas (2016) presented “Evaluation of Index-flood Approach Related Regional Frequancy Analysis Procedures”, they used Index-flood method for RFA(regional frequency analysis) to estimate the designs of hydrological structures at ungauged locations in river basins. It evaluates the performance of CIF(conventional Index Flood)method with LIF(Logarithmic Index Flood) method by the help experimental case studies. The result shows that the errors are highest for LIF method. The reason is lack of knowledge on theoretical form of RFD and selection of RFD is inappropriate.[6]

Lim and Voeller (2009) proposed “Regional Flood Estimations in Red River Using L-Moment-Based Index-Flood and *Bulletin 17B* Procedures”, they represented the regional flood frequency analysis of the Red River basin using L-moment-based index-flood method (LMIF).It detects the necessity of subdividing the basin into three main homogeneous regions. The results are better than the traditional methods. The investigation also illustrates the flexibility of the method in allowing flood estimations for a special regulated region.[7]

Guru and Jha (2015) presented “Flood Frequency Analysis of Tel Basin of Mahanadi River System,India using Annual Maximum and POT Flood Data”, carried out the site analysis using both the Annual Maximum and Peak over Threshold flood series data at two gauging sites (Kesinga and Kantamal) of Tel basin, Mahanadi river. The result shows that the values below 5% probability of exceedance are affecting the downstream regions. Keeping this criteria in view, the values are considered in the present work as POT values for both stations. The results are almost same compared to data used globally for flood forecasting.[8]

Burn et al. (1997) suggested “Regionalization of Catchments for Regional Flood Frequency Analysis”, they used flood frequency analysis which involves applying available of data of certain site in a particular cluster to be applied at sites where inappropriate or no data is available. These approach is a method to remove all the dissimilar and only to put in all the similar characteristics of the whole cluster of sites by usage of mathematical formulation based upon the hydrological and physiographical properties.[9]

Kumar and Chatterjee (2005) presented “Regional Flood Frequency Analysis Using L-Moments for North Brahmaputra Region of India”, they used L-Moment method which is used to obtain the homogeneity measures of a certain cluster of sites in a particular catchment and using these they estimated flood frequency data for gauged and ungauged sites which could be used for design of hydrological structures.[10]

Thorvat and Mujumdar (June 2011) presented” Design flood estimation for upper Krishna Basin through RFFA “, they carried out regional flood frequency analysis on upper Krishna Basin using flood index method and developed a relationship between mean annual peak flood and the catchment area and to use the same for the ungauged sites where flood data is not available or are inappropriate.[11]

III. STUDY AREA

The Sabarmati basin for which sufficient annual peak flood data at number of gauging station were available was selected at the selected area. The Sabarmati river basin has a maximum length of 300 km and maximum width of 105 km. The total catchment area of the basin is 21674 km^2 out of which , 4124 km^2 lies in Rajasthan state and the remaining 18550 km^2 in Gujarat. It is located between longitude of 72.5818° E and latitude of 23.0566° N. It originates from Dhebar Lake in Aravalli range of the Udaipur District of Rajasthan and meets the Gulf of Cambay of Arabian Sea. The major tributaries of this river basin are Watrak, Shedhi, Harnav, Guhai, Hathmati, Khari, Meshwo, Mazam and Mohar.

This study involves collecting data of Sabarmati river basin from State Water Data Centre, Gandhinagar. A flood frequency analysis has to be conducted using flood index method for which data like No. of gauging sites and gauging data i.e. catchment area and mean annual peak flood for each gauging site is required. For this study minimum No. of gauging site is 7 and minimum 10 years gauging data for each gauging site should be available.

3.1 Catchment Area

The catchment area data for the various watersheds for which the annual peak flood series are available have also been collected. The 12 catchments which are selected in the present study have catchment area ranging from 111.56 to 9127.14 sq. km.

3.2 Annual Peak Flood
The data of Annual Peak floods for the largest possible period for several catchments of Narmada Basin have been collected. Flood data of 12 catchments has been utilized in the present study, having record length more than or equal to 10 years, i.e. range of record length 12 to 34 years, for the flood estimation.

IV. METHODOLOGY

In present study, Flood Index Method has been utilized to carry out Regional Flood Frequency Analysis.

4.1 Index flood method
Index Flood method utilizes the data of the gauged catchments to evaluate a regional relationship from which the flood magnitudes of various return periods for ungauged catchments can be evaluated. The method requires only a single physiographic factor from ungauged catchment i.e. the catchment area. The description of the individual steps of Index Flood method is given below. Along with that it is said to be advantageous if we possess more amount of data as it helps to characterize a catchment area in a more proper way. After establishment of a successful relationship between various factors including catchment area, return period and mean peak annual flood it becomes easy for us to design heavy hydraulic structures at locations where data is available in an unorganized form or not at all available.

4.2 Selection of Gauged Catchments
As the data of the gauged catchments is required to be utilized for development of regional relationship, the first step is to identify those gauged catchments whose data can be used. These gauged catchments should have the similar physiographic, hydrologic and Metrologic characteristics as exists in ungauged catchments. The above written process can be performed by performing certain computation including computing errors for estimating upper and lower limits and using graphs provided through various scientific studies for performing homogeneity test which would be explained further in detail.

4.3 Data Requirement
The most important data which is required for the analysis with the Index Flood Method is the observed annual peak flood. In the present study the annual peak flood data from most of the gauging sites obtained by State Water Data Centre (SWDC) in Sabarmati Basin for as long a period is possible have been collected.

4.4 Base period determination
A time base period i.e. the longest period of record available for a certain gauging site is utilized in the analysis for obtaining results. In the present study a base period of 10 years i.e. data of only those sites have been considered for the analysis which were having records more than equal to 10 years.

4.5 Flood frequency curves
After establishing the length of record at each of the gauging site, the Flood Frequency Curves are drawn for each of the gauging site. Stepwise procedure to draw flood frequency curves is given as:-

- Arrange the Annual Peak Flood Values in ascending order and rank them.
- The corresponding plotting position for each flood value is then calculated using Gringorton Plotting Position Formula:

$$\mathbf{Pi} = \frac{(\mathbf{I} - \mathbf{0.44})}{(\mathbf{N} + \mathbf{0.12})}$$

Where, P_i is the Probability of exceedance of an event, I is the rank of the event, and N is the number of years of record. The value of probability obtained via using the mathematical formula actually determines the probability of exceedance of an event in terms of peak flood, for example at a certain gauged site, for the year 1999, the observed peak flood value is 7.08 cumecs, its rank in ascending order comes out to be one and the value of probability comes out to be 0.038 then the this represents that the probability of an event with 7.08 as the peak flood value can exceed this particular value at a probability of 0.038.

- Using the corresponding plotting positions, the reduced variate (y_i) for Gumbel's EV-1 distribution for any peak discharge value is calculated using the formula:

$$\mathbf{y_i = - ln\,[- ln\,(P_i)\,]}$$

- The principle point about performing the computation in regards to the reduced variate is that the data that we possess for different gauged sites appears to be scattered therefore if we do not characterize the same then it would be difficult for us to trace any sort of relationship with the data available to us therefore we characterize the data in a certain form of distribution curve to make our process easy and to trace a perfect relationship with the variables available to us in a random format.

- Using the ranked annual maximum flood series and the corresponding plotting positions, the frequency curves have been developed by plotting the peak discharge value against the values of Gumbel's EV-1 reduced variate on an ordinary graph paper for each gauging site. The line is drawn through the plotted points using linear regression technique to result into a flood frequency curve.
- The suitability of the straight line fitted for the observations on graph paper as mentioned above, is required to be checked as envisaged by Dalrymple (1960). The check has been performed in the study by constructing 95% confidence interval using the upper and lower confidence intervals as given by Hann (1977) and are defined by following equation :

$Q_{KL} = Q_K - S_{QK} \cdot t_{(1-\alpha/2),(N-2)}$

$Q_{KU} = Q_K + S_{QK} \cdot t_{(1-\alpha/2),(N-2)}$

- The standard error S_{QK} can be estimated by the following equation as given by Hann (1977):

$$\mathrm{SQK} = \mathrm{S}[1 + \frac{1}{N} + \frac{(Yi - YM)^2}{\sum_{i=1}^{N}(Yi - YM)^2}]^{0.5}$$

$$\mathrm{S} = [\frac{\sum_{i=1}^{N}(\mathrm{Qi} - \mathrm{Qi}')^2}{(N-2)}]^{0.5}$$

Where, Q_i is the ith value of observed peak flood series, $\mathbf{Q_i}'$is the ith value of computed peak flood, N is the number of observations considered for the regression, y_i is the ith valueof EV-1 reduced variate, and $\bar{y}$ is the mean of N values of EV-1 reduced variate

- The flood frequency curves have been developed for all the 16 gauging stations following the above mentioned procedure and the straight lines of the following form have been fitted :

$Q_T = a + b\, Y_T$

Where, YT is the reduced variate, QT is flood magnitude for return period of T years and a, b, are the constants.

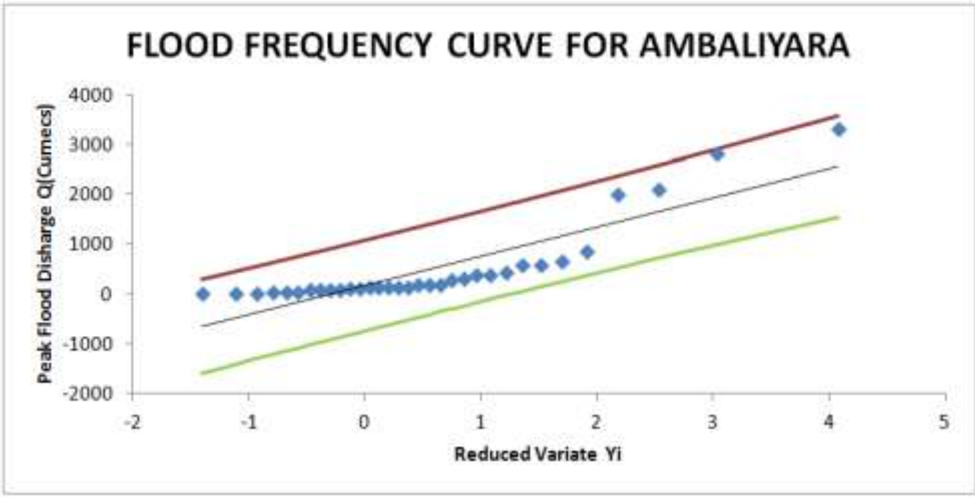

Fig. 4.1: Flood Frequency Curve for Ambaliyara

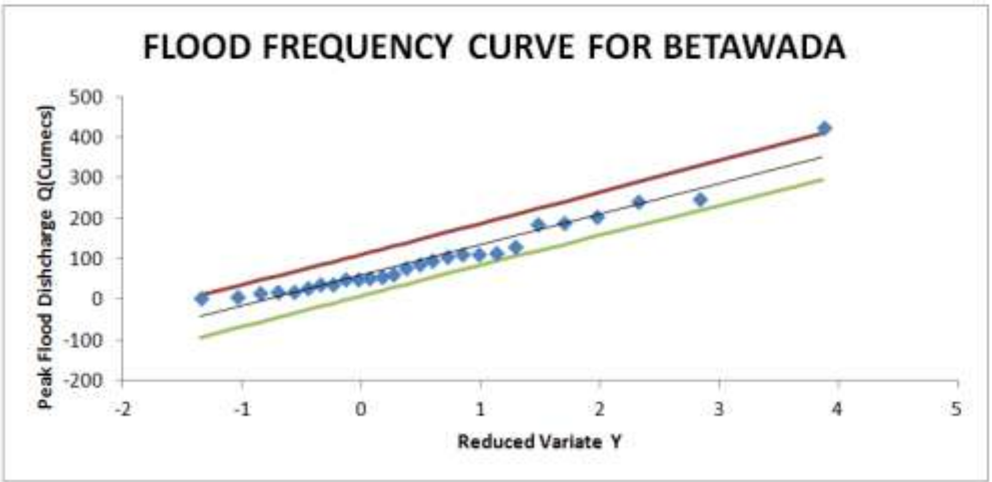

Fig. 4.2: Flood Frequency Curve for Betawada

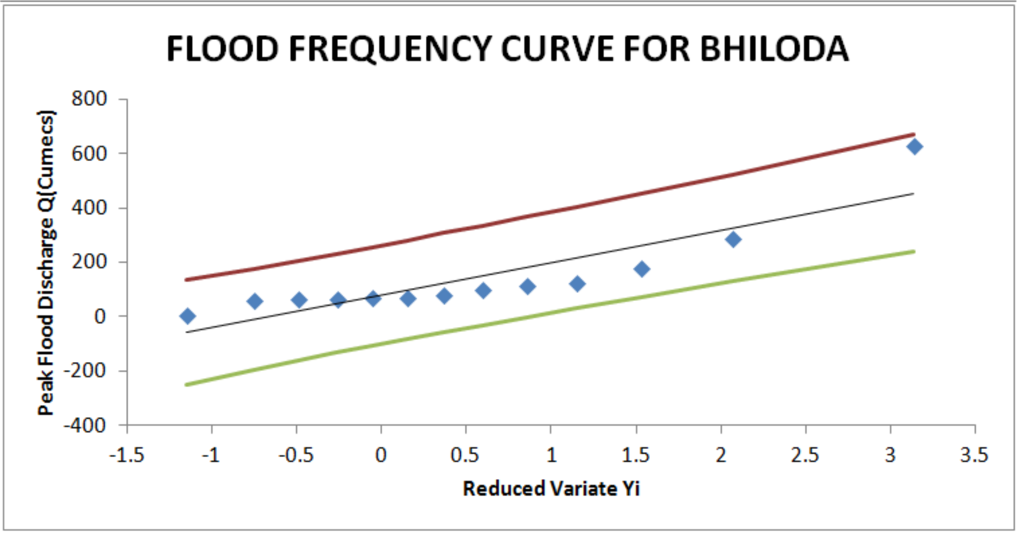

Fig. 4.3: Flood Frequency Curve for Bhiloda

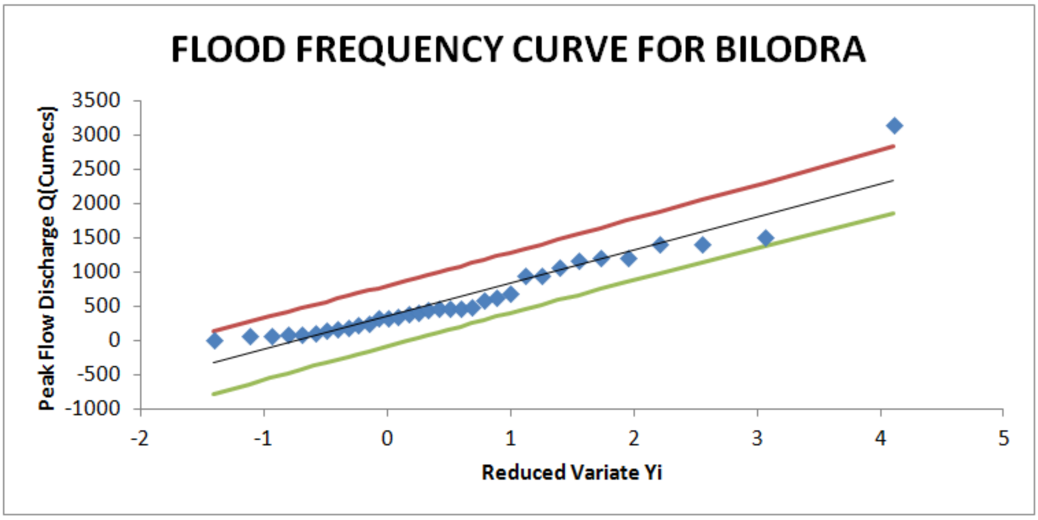

Fig. 4.4: Flood Frequency Curve for Bilodra

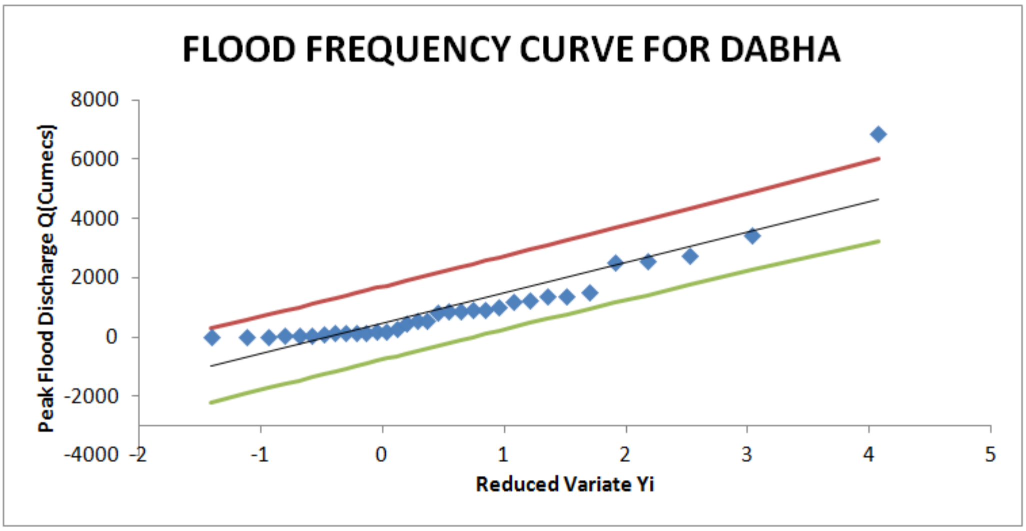

Fig. 4.5: Flood Frequency Curve for Dabha

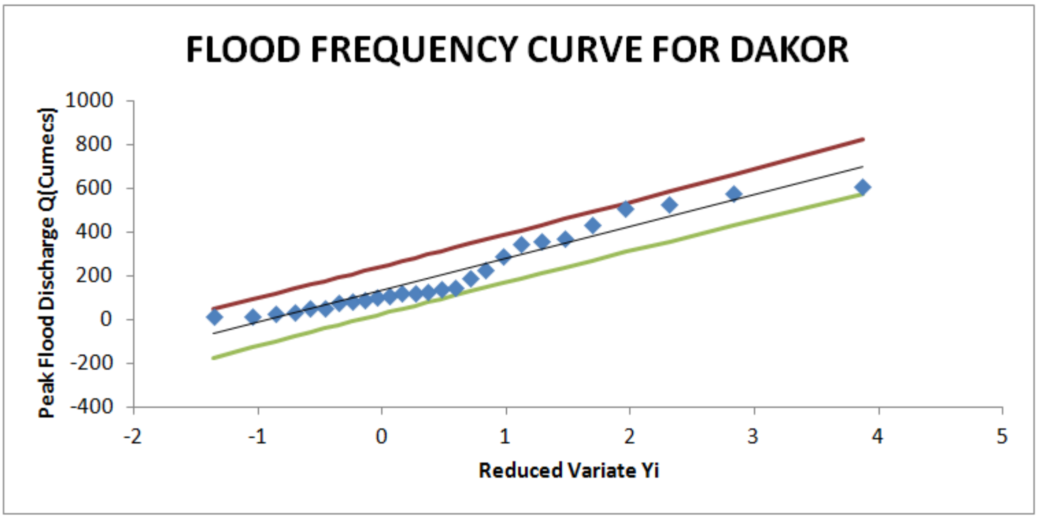

Fig. 4.6: Flood Frequency Curve for Dakor

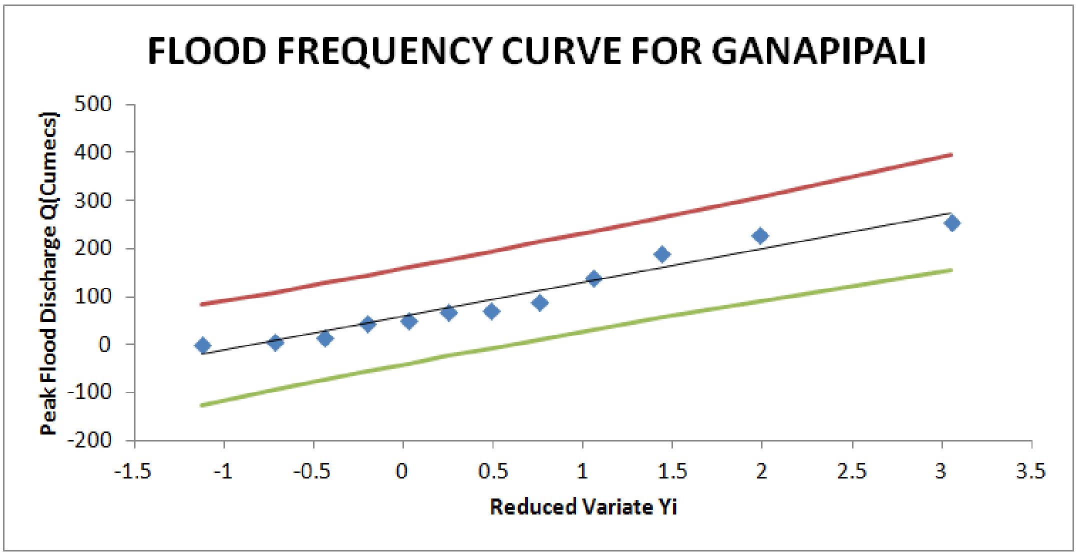

Fig. 4.7: Flood Frequency Curve for Ganapipali

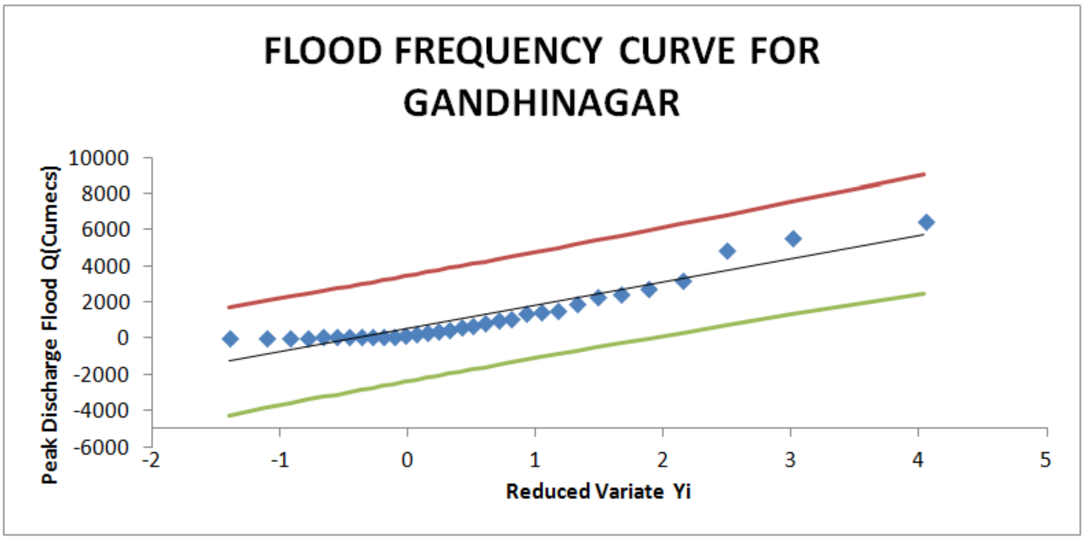

Fig. 4.8: Flood Frequency Curve for Gandhinagar

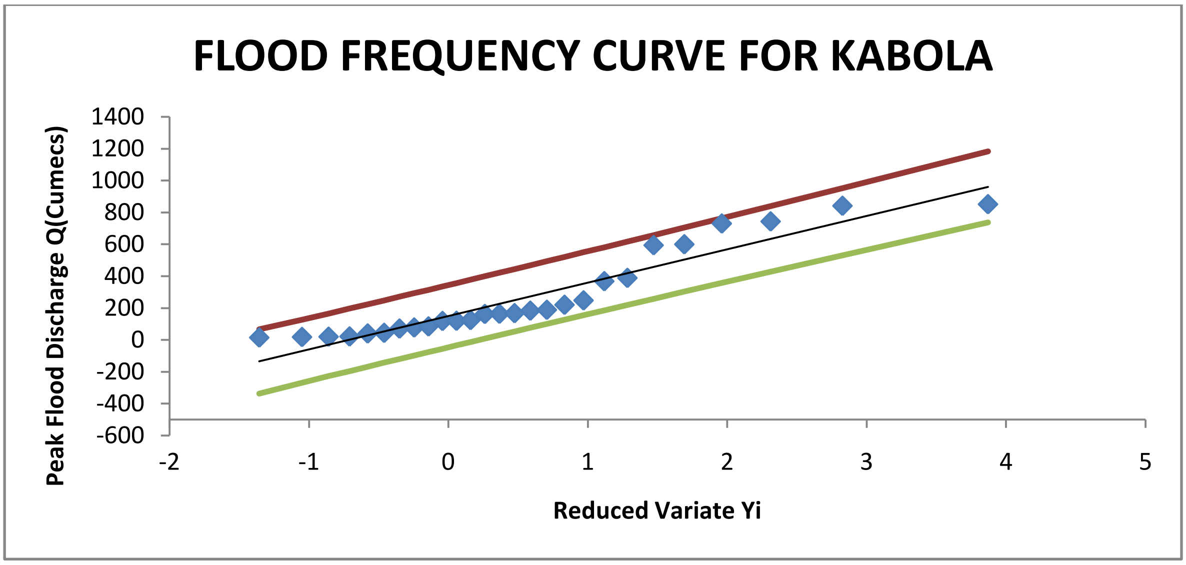

Fig. 4.9: Flood Frequency Curve for Kabola

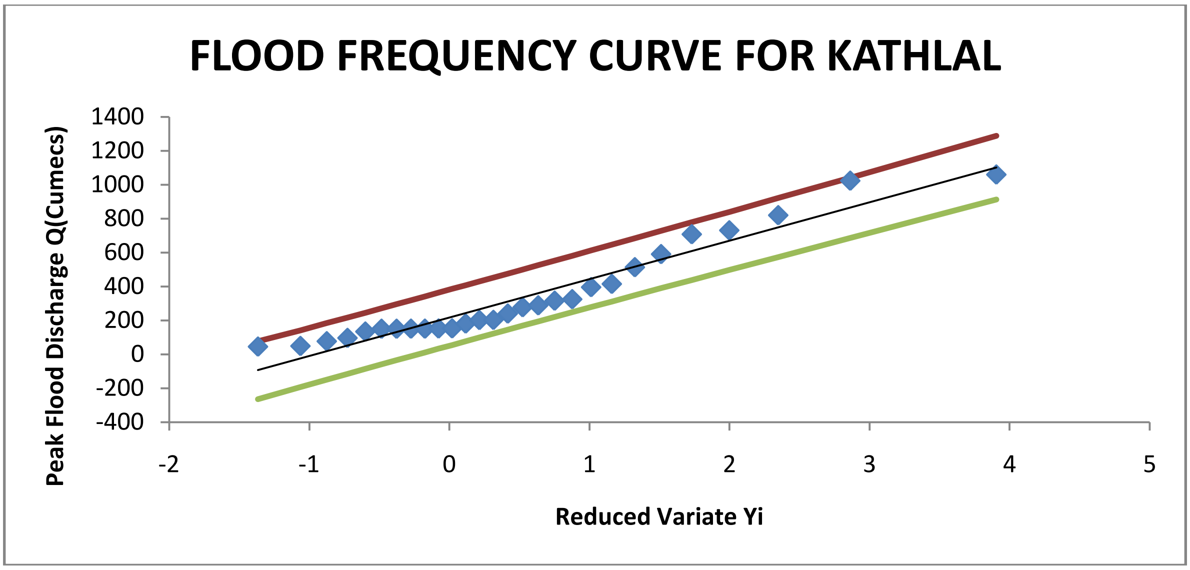

Fig. 4.10: Flood Frequency Curve for Kathlal

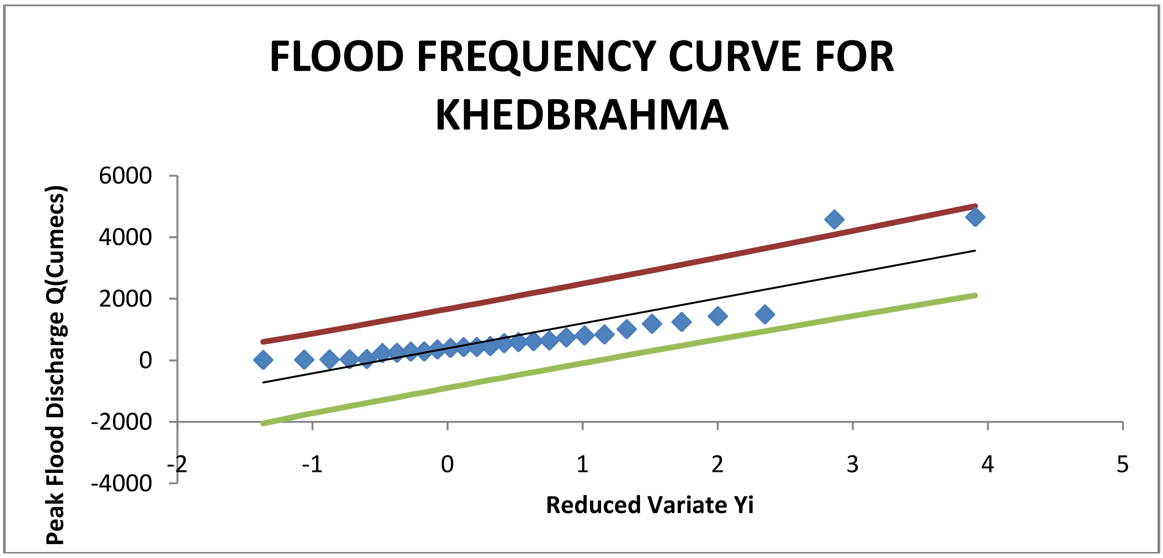

Fig. 4.11: Flood Frequency Curve for Khedbrahma

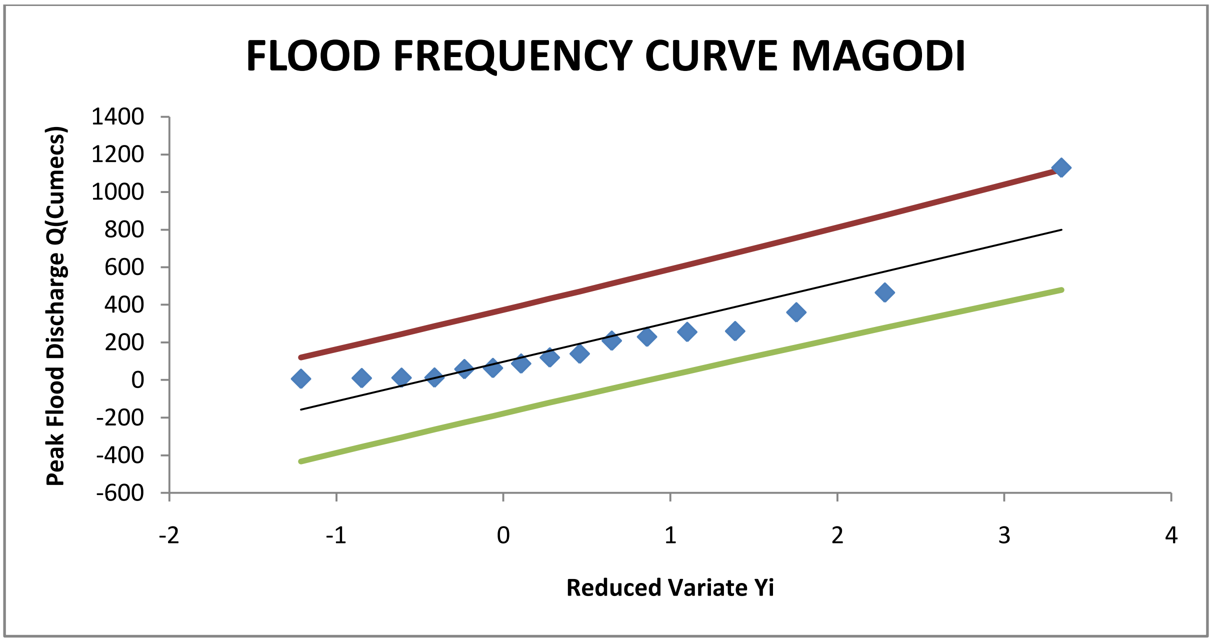

Fig. 4.12: Flood Frequency Curve for Magodi

Table 4.1: Equation of Frequency Curves for Different Catchments

Sr.No.	Station	Equation of Frequency Curve	Correlation Coefficient r	r^2
1	Ambaliyara	QT=585.19YT+167.29	0.878350727	0.7715
2	Betawada	QT=75.404YT+59.916	0.973190629	0.9471
3	Bhiloda	QT=119.01YT+80.521	0.884477247	0.7823
4	Bilodra	QT=482.54YT+361.12	0.952365476	0.907
5	Dabha	QT=1021.5YT+471.85	0.91874915	0.8441
6	Dakor	QT=145.91YT+134.03	0.96783263	0.9367
7	Ganapipali	QT=70.9YT+58.606	0.977343338	0.9552
8	Gandhinagar	QT=1293.6YT+537.41	0.944828027	0.8927
9	Kabola	QT=209.64YT+148.35	0.95036835	0.9032
10	Kathlal	QT=226.51YT+215.57	0.968813708	0.9386
11	Khedbrahma	QT=812.71YT+384.17	0.875214259	0.766
12	Magodi	QT=209.93YT+97.708	0.910439454	0.8289

4.6 Homogeneity Test

The homogeneity test is summarized in the following steps :

- Read the values of 10 year return flood for each gauging site using developed frequency curves.
- Find the 10 year ratio by dividing each 10 year flood value by mean annual flood ($Q_{2.33}$).
- Determine regional average by taking mean of all 10 year ratio values.

Table 4.2: Computation of Frequency Ratio

Sr.No.	Station	Equation of Regression Line	Q2.33	Q10	Q10/Q2.33=α
1	Ambaliyara	QT=585.19YT+167.29	505.8740955	1484.182	2.933896931
2	Betawada	QT=75.404YT+59.916	103.5438732	229.6027	2.21744359
3	Bhiloda	QT=119.01YT+80.521	149.3787953	348.3372	2.331905375
4	Bilodra	QT=482.54YT+361.12	640.3120051	1447.012	2.259854944
5	Dabha	QT=1021.5YT+471.85	1062.877963	2770.6	2.606696462

6	Dakor	QT=145.91YT+134.03	218.4518209	462.3811	2.116627341
7	Ganapipali	QT=70.9YT+58.606	99.62791147	218.157	2.189718125
8	Gandhinagar	QT=1293.6YT+537.41	1285.871843	3448.485	2.681826492
9	Kabola	QT=209.64YT+148.35	269.6452542	620.117	2.299751236
10	Kathlal	QT=226.51YT+215.57	346.626039	725.3007	2.092458793
11	Khedbrahma	QT=812.71YT+384.17	854.3887229	2213.044	2.590206855
12	Magodi	QT=209.93YT+97.708	219.1710448	570.1276	2.601290757
				Mean α=	2.410139742

- Calculate the discharge and corresponding return period for the modified values of 10 year flood to obtained by multiplying the regional average with mean annual flood ($Q_{2.33}$) for each gauging site.
-

Table 4.3: Homogeneity Test Computation Details

Sr.No.	Station	QT=ᾱ Q2.33	EQUATION FOR COMPUTATION OF YT	YT	T (YEARS)
1	Ambaliyara	1219.2272	YT=(QT-167.29)/585.19	1.7976	6.54844660
2	Betawada	249.55520	YT=(QT-59.916)/75.404	2.51497	12.8711011
3	Bhiloda	360.02377	YT=(QT-80.521)/119.01	2.34856	10.9770330
4	Bilodra	1543.2414	YT=(QT-361.12)/482.54	2.44978	12.0913587
5	Dabha	2561.6844	YT=(QT-471.85)/1021.5	2.04584	8.24565279
6	Dakor	526.49941	YT=(QT-134.03)/145.91	2.68980	15.2318783
7	Ganapipali	240.11718	YT=(QT-58.606)/70.9	2.56010	13.4414783
8	Gandhinagar	3099.1308	YT=(QT-537.41)/1293.6	1.98021	7.75504202
9	Kabola	649.88274	YT=(QT-148.35)/209.64	2.39235	11.4452351
10	Kathlal	835.41719	YT=(QT-215.57)/226.51	2.73651	15.9356728
11	Khedbrahma	2059.1962	YT=(QT-384.17)/812.71	2.06103	8.36386285
12	Magodi	528.23284	YT=(QT-97.708)/209.93	2.05080	8.28400337

- The computed return period values are to be plotted against the length of record available for the gauging stations.
- The plotted points for all the stations under the consideration should fall within the upper and lower regional confidence limits T_U and T_L for passing the homogeneity test. Any station for which the plotted point lies outside the envelop curve fails in homogeneity test and thus excluded from analysis.

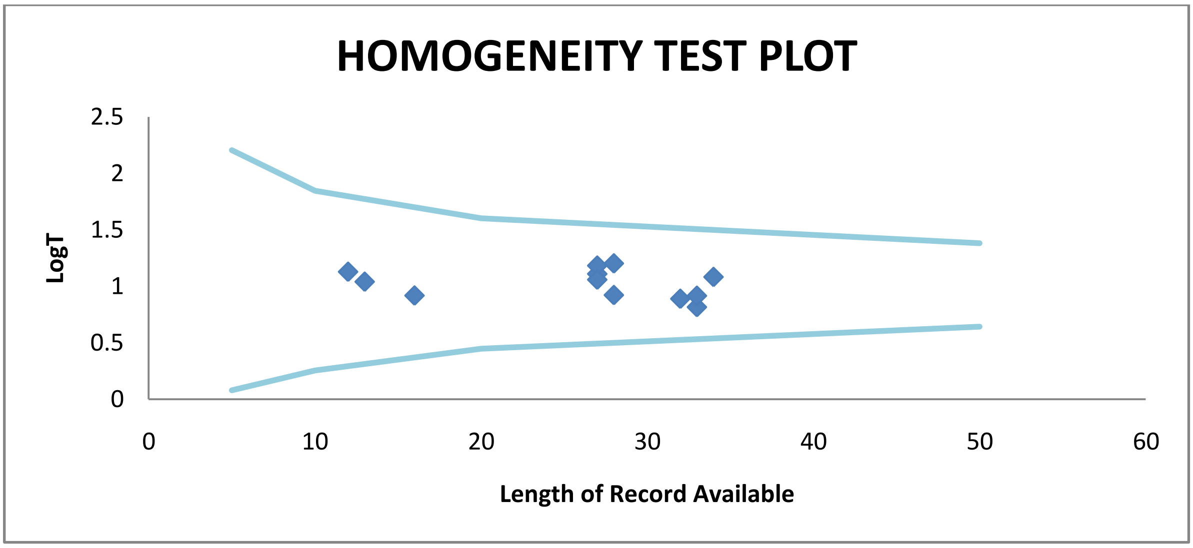

Fig. 4.13: Homogeneity Test Plot

4.7 Relationship of Mean Annual Flood and Catchment Area

After performing the homogeneity test a relationship of the following type is required to be developed as the further part of analysis:

$$Q_{2.33} = C\,A^{n}$$

Where, $Q_{2.33}$ is the mean annual flood value, A is the catchment area, and C and n are the region constants.

4.8 Regional Flood Frequency Relationship

The final step is to develop the regional flood frequency relationship for determining the values of flood for different return periods for ungauged catchments. This relationship can be developed using following sub steps :

- Using frequency curves the flood values of different return periods viz., 5, 10, 20, 50, 100, 200, 500, 1000 years etc. are read for each gauging site.
- Estimate the flood ratios for selected return periods by dividing the flood magnitudes obtained in step I with site specific mean annual flood value.
- The estimated flood ratios obtained in step II are arranged in ascending or descending order of magnitude and the median flood ratio value for each recurrence interval is noted.

Table 4.4: Flood Ratios for different Return Periods

Q5/Q2.33	Q10/Q2.33	Q20/Q2.33	Q50/Q2.33	Q100/Q2.33	Q200/Q2.33	Q500/Q2.33	Q1000/Q2.33
2.06581	2.9338969	3.7665865	4.8444178	5.65210069	6.45683647	7.51853251	8.320937229
1.670958	2.2174436	2.7416456	3.4201713	3.92863083	4.43523508	5.10360319	5.608739978
1.73404	2.3319054	2.9053919	3.6477113	4.20397526	4.7582095	5.48941635	6.042045153
1.694332	2.2598549	2.8023182	3.5044813	4.03065379	4.55490631	5.24655796	5.769291896
1.885483	2.6066965	3.2985014	4.1939719	4.86500108	5.53358176	6.41564701	7.082291023
1.615396	2.1166273	2.5974203	3.2197574	3.68611152	4.15076398	4.76378467	5.227091185
1.655678	2.1897181	2.7019822	3.3650555	3.86193562	4.35700272	5.01014974	5.503782789
1.926889	2.6818265	3.4059806	4.3433239	5.0457307	5.74557459	6.66888571	7.366702374
1.71632	2.2997512	2.8593929	3.5837917	4.12662662	4.66748084	5.38103528	5.920322825
1.602076	2.0924588	2.5628453	3.1717125	3.62797268	4.0825681	4.68232042	5.135599019
1.876396	2.5902069	3.2749118	4.161192	4.82533438	5.48705338	6.36006595	7.019868164
1.882504	2.6012908	3.2907681	4.1832259	4.85199734	5.51832859	6.39742615	7.061827252
1.72518	2.3158283	2.8823924	3.6157515	4.16530094	4.71284517	5.43522582	5.981183989

- The median flood ratio value is plotted against the reduced variate y for Gumbel EV -1 distribution to produce the regional flood frequency relationship. The developed flood frequency relationship is of the following form :

$$\frac{\mathbf{QT}}{\mathbf{Q2.33}} = \mathbf{a + b\,YT}$$

Where, Q_T is T year flood, $\bar{Q}$ is the mean annual flood ($Q_{2.33}$), Y_T is the EV-1 reduced variate, a and b are constants.

V. CONCLUSION

- The Regional Flood Frequency relationship developed by Index flood method is :

$$\frac{\mathbf{QT}}{\mathbf{Q2.33}} = \mathbf{0.7871YT + 0.5446}$$

- Relationship of Mean Annual Flood and Catchment Area:

$$\mathbf{Q_{2.33}=2.8223*A^{0.7199}}$$

- The Gumbel's Extreme Value Type I distribution more closely fits the annual flood data at most of the gauging sites of Sabarmati Basin.
- Further research is necessary to improve regional mean values. In this study the regional mean i.e $Q_{2.33}$ depends largely on catchment area. However $Q_{2.33}$ will be dependent on other catchment characteristics such as drainage density, slope of catchment, land use & land cover.

ACKNOWLEDGEMENTS

We would like to extend our sincere gratitude towards **Dr. Paresh Patel** (H.O.D., Civil Department) to give us this opportunity to do this wonderful project. We would also like to thank our subject guide **Prof. Amit Dubey**to help us out whenever required. We would also like to thank State Water Data Centre, Gandhinagar for providing necessary data of gauging sites which was required for our project work.

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International Journal of Engineering Science Invention (IJESI) is UGC approved Journal with Sl. No. 3822, Journal no. 43302.

Megh Modi. "Regional Flood Frequency Analysis: A Case Study of Sabarmati River Basin ." International Journal of Engineering Science Invention (IJESI) 6.7 (2017): 55-65.